J. Asi. Reha. Sci.3(2):17-22,2020

The Journal of Asian Rehabilitation Science

Original Article

Brain Regions Activated During Visual Motor Illusion of The Ankle Joint Movement

KATSUYA SAKAI, RPT, MS[1, 2], YUMI IKEDA, RPT, PhD[2], KAZU AMIMOTO, RPT, PhD[2]
KEISUKE GOTO, RPT, MS[2], KENJI MORIKAWA, RPT, MS[2], KEN KUMAI, RPT, MS[2]

1) Faculty of Healthcare Sciences, Chiba Prefectural University of Health Sciences (645-1, Nitonacho, Chuo-ku, Chiba-city, Chiba,116-8551, Japan)
2) Graduate School of Human Health Sciences, Tokyo Metropolitan University, Japan

Abstract. [Purpose] This study sought to localize the brain activity prompted by visual motor illusion (VMI) of the ankle movement. [Participants and Methods] We randomly applied VMI condition to the left and right lower limbs of 13 healthy subjects. The VMI condition required watching a video to induce VMI; the recording featured an ankle dorsiflexion movement on the non-measuring side in the first-person perspective. The left and right VMI conditions were measured three sets using a rest-task-rest block design using functional near-infrared spectroscopy. Oxygenated hemoglobin (oxy - Hb) during rest and task was measured under two conditions. Oxy - Hb of the two conditions were calculated average values of three sets and compared left and right VMI condition. During the VMI condition, a visual analog scale (VAS) was evaluated the degree of kinesthetic illusion. VAS of both VMI condition was compared using t test. [Results] VAS of the left VMI condition was higher when compared with the right VMI condition. In both conditions, oxy - Hb in the premotor area was significantly increased during the VMI condition. [Conclusion] VMI of the ankle movement induces increased oxy - Hb in the premotor area of healthy subjects.

Key words: Visual motor illusion, functional near-infrared spectroscopy, ankle joint movement

(This article was submitted May.13, 2020, and was accepted June.11, 2020)

1. INTRODUCTION

Visual motor illusion (VMI) is to evoke a kinesthetic sensation by viewing images of oneself performing physical exercise while the body is at rest[1]. Previous research has explored the clinical applications of VMI. It has been reported that VMI was improved range of motion and muscle activity of upper limb in stroke hemiparesis[2]. We have explored whether VMI can be applied to the lower limbs. An investigation conducted by the authors of the present study found that VMI improved the range of ankle dorsiflexion and walking speed of patients with stroke hemiparesis improved following VMI[3]. VMI improves the motor function of stroke patients by inducing an illusion while a body is at rest.

Previous research has explored the mechanism of VMI. Motor evoked potential obtained from the anterior tibial muscle increased by VMI of the ankle joint movement and revealed that the excitability of the primary motor area (M1) increased using transcranial magnetic stimulation[4].

Based upon these reports indicating that VMI involving ankle joint movement increases the excitability of the M1 and improves the motor function, we hypothesize that brain regions typically associated with

*Corresponding author: KATSUYA SAKAI (sakai.katsuya@gmail.com)

movement will be observed during VMI. The purpose of this study was to identify specific regions of brain activity area during VMI of ankle joint movement.

2. SUBJECTS AND METHODS

The subjects recruited for this study were 13 healthy adults (mean age, 25.3 ± 5.8 years; 10 men, 3 women). None of the subjects had any history of orthopedic or neurological disease. The purpose of the study was explained to the subjects, and written consent was obtained in compliance with the Declaration of Helsinki. This study was conducted with the approval of the institutional ethics committee of Tokyo metropolitan university (approval number: 17045).

The subjects were randomly assigned to one of two experimental conditions: left or right VMI. The video was recorded prior to the experiment with the camera of a tablet (iPad Pro, Apple). The individual in the video was seated during filming to allow for a first-person perspective. The recording was then transposed, rotated, and flipped horizontally with video reversal software to permit subject participants to view the ankle dorsiflexion as if it were performed on the subject's measuring side (Figure 1). The side being measured was positioned so that the ankle joint overlapped with the image of the ankle joint of the non-measuring side shown on the video.

Outcomes were brain activity during VMI and visual analog scale (VAS) scores. Brain activity was measured using functional near-infrared spectroscopy (fNIRS, LABNIRS, Shimadzu Co., Ltd). VAS was used as an index of the degree of kinesthetic illusion.

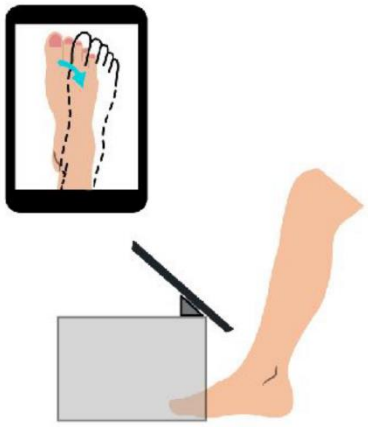

Figure 1. Set of VMI condition

This figure is the right VMI condition. The tablet was placed in front of the foot, and the tablet was set so that the actual foot could not be seen. The video is a reverse image of the left ankle joint movement.

Functional near-infrared spectroscopy

fNIRS was measured using a rest-task-rest block design. Each set of a block was performed with a rest of 15 seconds followed by a 30-seconds task and another break of 15 seconds, respectively. A block consisted of three sets. Oxygenated hemoglobin (oxy - Hb) during rest and task were recorded using fNIRS. The sampling rate of fNIRS was 10Hz. The regions of interest (ROI) for the fNIRS measurement were informed by motor association area; they included the bilateral prefrontal cortex (PFC), premotor cortex (PMC), M1, and supplementary motor area (SMA). The ROIs were measured using a total of 50 channels. The position of the probe was determined using the international 10-20 methods to maintain the consistency of measurement positions across participants[5]. The channels were arranged vertically in a 7 × 4 grid so as to cover from the front right corner to the center groove. An additional three channels were arranged in front of the grid such that the channels were in a convex configuration (Figure 2). The channels used NIRTRAC software (3 SPACE®, FASTRAK®, Polhemus Co., Ltd.) to ascertain which brain region corresponded to its respective channel. The channels then converted these coordinates into the location

each of the 50 channels in an estimated MNI space by NIRS-SPM[6]. Figure 2 shows the results of the channels. In this study of the left VMI condition, the right hemisphere was target, and in the case of the right VMI condition, the left hemisphere was target.

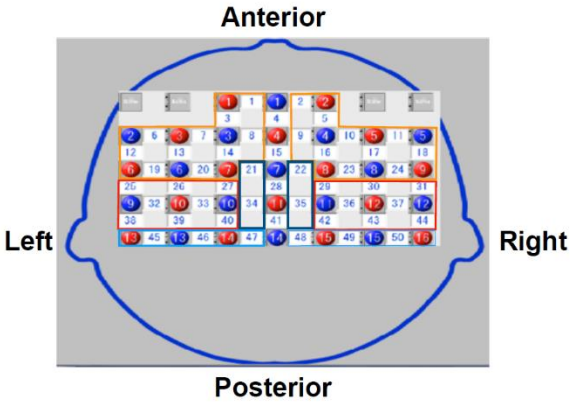

Figure 2. The measurement channels of fNIRS
The orange line indicates channels corresponding to the prefrontal cortex: 1-3, 5-8, 9-14, 16-20, 23, 24. The red line indicates channels corresponding to the premotor cortex: 25-27, 29-31, 32, 33, 36, 37, 38-40, 42-44. The blue line indicates the primary motor area is 45-47, 48-50. The green line indicates that supplementary motor area is 21, 22, 34, 35.

In analyses, the oxy - Hb was filtered and smoothed to remove noise. The band pass filter was set to 0.1 - 1.0 Hz and three sets were averaged. For brain activity using fNIRS, the oxy-Hb for each ROI was calculated as the mean value of activity at rest and then during each task. As fNIRS features an approximate delay of 5 seconds before recording the oxy - Hb value[7], recording and analysis during rest and task began 5 seconds after its start.

Visual analog scale
The subjects were asked to point to a position on a 100 mm line that represented the level of illusory movement; 0 mm indicated that the subject did not experience an illusion, while 100 mm indicated that the subject experienced a kinesthetic illusion and felt as though his or her leg was moving.

Statistical analyses
In statistical analyses, for oxy - Hb values, the two-way analysis of variance of two condition (left VMI condition, right VMI condition) and block (rest, task) was conducted in each ROI (PFC, PMC, M1, SMA). A t-test was used to compare whether there was a difference in vas under the right and left VMI conditions. Spearman's correlation analysis was conducted to examine the relationship between the VAS and oxy – Hb value of target ROI.

3. RESULTS

Indicating the degree of kinesthetic illusion experienced during VMI, the mean VAS score of the left VMI condition was 67.2 ± 13.5 mm, while that of the right VMI condition was 56.9 ± 11.3 mm. The left VMI condition was significantly higher compared to the right VMI condition ($t(12) = 2.72$, $p = 0.019$, Table 1).

Table 1. The oxy - Hb of left and right VMI condition and VAS score

Condition	Block	PFC	PMC	SMA	M1	VAS
Right VMI condition	Rest	0.013 ± 0.058	0.014 ± 0.044	0.002 ± 0.020	-0.002 ± 0.014	67.2 ± 13.5 †
	Task	0.034 ± 0.081	0.033 ± 0.026 *	0.008 ± 0.018	-0.004 ± 0.013	
Left VMI condition	Rest	-0.001 ± 0.054	0.014 ± 0.068	-0.005 ± 0.016	0.001 ± 0.008	56.9 ± 11.3
	Task	0.037 ± 0.090	0.037 ± 0.090 *	-0.002 ± 0.008	-0.001 ± 0.008	

Unit: oxy-Hb : mm・Mm. VAS: mm. *p<0.05 (vs Rest). †p<0.05 (vs left VMI condition).
Prefrontal cortex: PFC, Premotor cortex: PMC, Supplementary motor area: SMA, Primary motor area: M1

A significant main effect was observed in both sides of the PMC between conditions (Table 1, left VMI condition: F (1, 25) = 8.09, p = 0.009, right VMI condition: F (1, 33) = 4.93, p = 0.034). However, no significant interaction was observed. In other ROIs, no significant main effects and interactions were observed (p > 0.05). The mapping image using fusion software is shown (Figure 3).

Weak, but not significant correlations were observed between the VAS and PMC (left VMI condition: p = 0.378, r = 0.27, right VMI condition, p =0.420, r = 0.25).

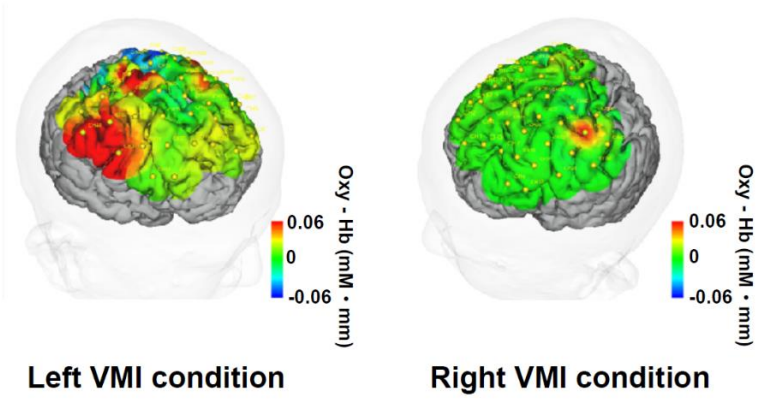

Figure 3. The mapping of left and right VMI condition
The left VMI condition was widely active compared with the right VMI condition.

4. DISCUSSION

This study sought to localize the brain activity prompted by VMI of the ankle joint movement. The VAS of the left VMI condition was significantly higher compared with right VMI condition. On both VMI condition, the PMC was activated on the side contralateral to the measurement side.

Previous research on the upper limb VMI was reported PMC, SMA, parietal area[8]. Christensen et al. reported that applying repetitive transcranial magnetic stimulation to the PMC induced the perception of motion, reportedly recruiting a top-down process that involves sensory-motor integration[9]. The tendon vibration stimulation study reported that a kinesthetic-illusion-induced increase in the cerebral blood flow rate in the PMC[10]. In this study, the PMC was activated during both conditions, similar to findings of previous studies. In the mapping image, the left VMI condition was wildly actived than the right VMI condition. The frontal-parietal network of the right hemisphere has also been reported to be involved[11]. Therefore, the right hemisphere thought that cerebral blood flow increased widely.

The intensity of the illusion was significantly higher under the left VMI condition compared with right VMI condition. The frontal-parietal network of the right hemisphere has also been reported to be involve[11]. Therefore, we can conclude that the illusion intensity in the left VMI condition may have been high. The VAS scores in this study indicated similar degrees of kinesthetic illusion as previously reports[4,5], and this degree of kinesthetic illusion is considered sufficient to induce kinesthetic illusion.

Our study features several limitations. As found in previous investigations, brain activity during kinesthetic illusion was observed both in the PMC and the parietal area. In this study, the limited number of channels prevented our measurement of the parietal region.

In conclusion, we used fNIRS to identify brain activity elicited by VMI of the ankle joint movement. We found that oxy - Hb in the PMC increases during kinesthetic illusion.

Funding and Conflict of interest

The authors have no conflicts of interest to declare for this research.

Acknowledgement

The authors would like to thank research members of Tokyo Metropolitan University for their help in the study.

REFERENCES

1) Kaneko F, Yasojima T, Kizuka T.: Kinesthetic illusory feeling induced by a finger movement movie effects on corticomotor excitability. Neuroscience, 2007, 49: 976-984.
2) Kaneko F, Inada T, Matsuda N.: Acute effect of visually induced kinesthetic illusion in patients with stroke: a preliminary report. Inter. J. Neurorehabilitation, 2016, 3: 212.
3) Sakai K, Ikeda Y, Amimoto K.: Effect of kinesthetic illusion induced by visual stimulation on ankle dorsiflexion dysfunction in a stroke patient: ABAB single-case design. Neurocase, 2018, 24: 245-249.
4) Aoyama T, Kaneko F, Hayami K, Shibata E.: The effects of kinesthetic illusory sensation induced by a visual stimulus on the corticomotor excitability of the leg muscles. Neurosci. Lett, 2012, 514: 106-109.
5) Towle V. L, Bolanos J, D. Suarez K, et al.: The spatial location of EEG electrodes ：locating the best-fitting sphere relative to cortical anatomy. Electroencephalogr Clin Neurophysiol, 1993, 86: 1-6.
6) Tsuzuki D, Jurcak V, Singh A. K, et al.: Virtual spatial registration of stand-alone fNIRS data to MNI space. NeuroImage, 2006, 34: 1506-1518.
7) Jasdzewski G, Strangman G, Wagner J, et al.: Differences in the hemodynamic response to event-related motor and visual paradigms as measured by near-infrared spectroscopy. NeuroImage, 2003, 20: 479-488.
8) Kaneko F, Blanchard C, Lebar N, et al.: Brain regions associated to a kinesthetic illusion evoked by watching a video of one's own moving hand. PLoS One, 2015, 10, e0131970.
9) Christensen M. S, Lundbye-jensen J, Geertsen S.S, et al.: Premotor cortex modulates somatosensory cortex during voluntary movements without proprioceptive feedback. Nat. Neurosci, 2007, 10: 417-419.
10) Imai R, Hayashida K, Nakano H.: Brain activity associated with the illusion of motion evoked by different vibration stimulation devices: an NIRS study. J. Phys. Ther. Sci, 2014, 26: 1115-1119.
11) Naito E, Morita T, Amemiya K.: Body representations in the human brain revealed by kinesthetic illusions and their essential contributions to motor control and corporeal awareness. Neurosci. Res, 2016, 104: 16-30.